Targets in Superheavy Element Experiments

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MOTIVATIONS AND GOALS

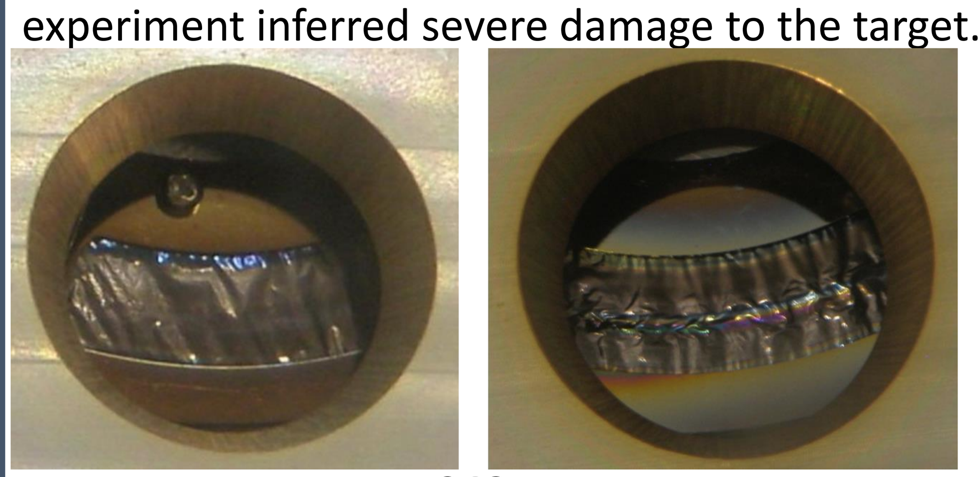
Study of superheavy elements (SHE, Z = 112 – 118) are limited by their low production cross-sections, a few picobarns (1 pb = 10^{-36} cm^2) or less. Continued investigation in this regime requires higher beam intensities than are currently available (1 pμA). As a result , targets capable of surviving higher power ion beams are a key issue.

The following goals motivate this work—

1. Investigation of severely damaged target in recent element 115 experiment.
2. Modelling of target under exposed to intense heavy ion-beams (1 pμA) using computer simulations.
3. Use of computer simulation to investigate targets used at other facilities that study SHEs .
4. Re-design of target and characterization in recent ^{255}Lr experiment.

ELEMENT 115 EXPERIMENT

The target integrity was measured during a recent element 115 experiment with a combination of the Rutherford detector rates (Rutherford detectors located downstream of the target) and the beam current measurements (Faraday cup located upstream of the target. Beam intensities in this experiment were as high as 1.0 pμA. An observed drop in the Rutherford rates with stable beam current during the experiment inferred severe damage to the target.



Left: Before photograph of $^{243}Am_2O_3$ target. **Right:** Target after taken after ^{48}Ca beam intensity increased to 1.0 pμA. Damage suffered from the beam is clear.

Simulation of $^{243}Am_2O_3$ target

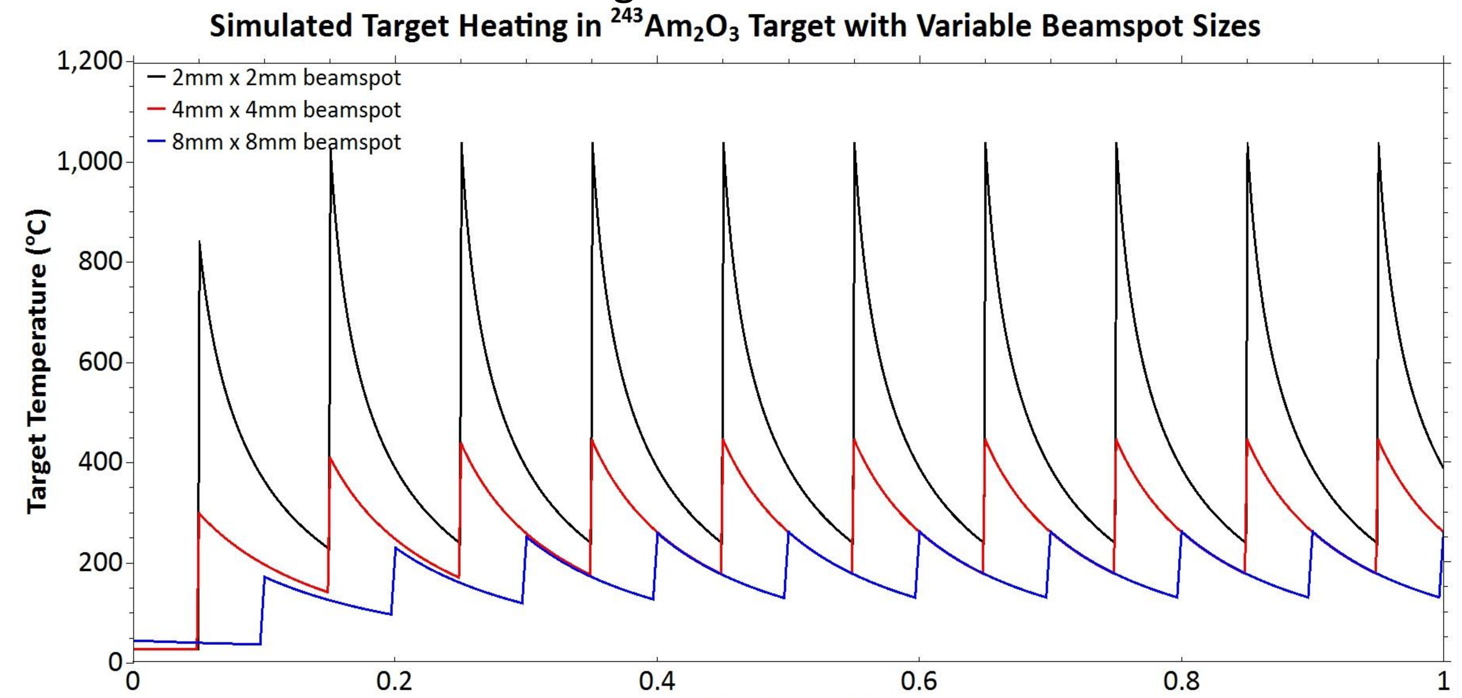
Computer simulations were used to model target heating and understand how the damage occurred to the target.

Below: Plot of simulated heating of the $^{243}Am_2O_3$ target used in the element 115 experiment. Various beamspots were simulated. Spikes in temperature indicate target passing through beamspot. The target is then cooled via combination of blackbody radiation and convective cooling.

Factors Considered in Simulated Target Heating

- Beam intensity
- Beamspot size
- dE/dx of ion beam
- Target wheel rotation frequency
- Convective cooling
- Blackbody radiation

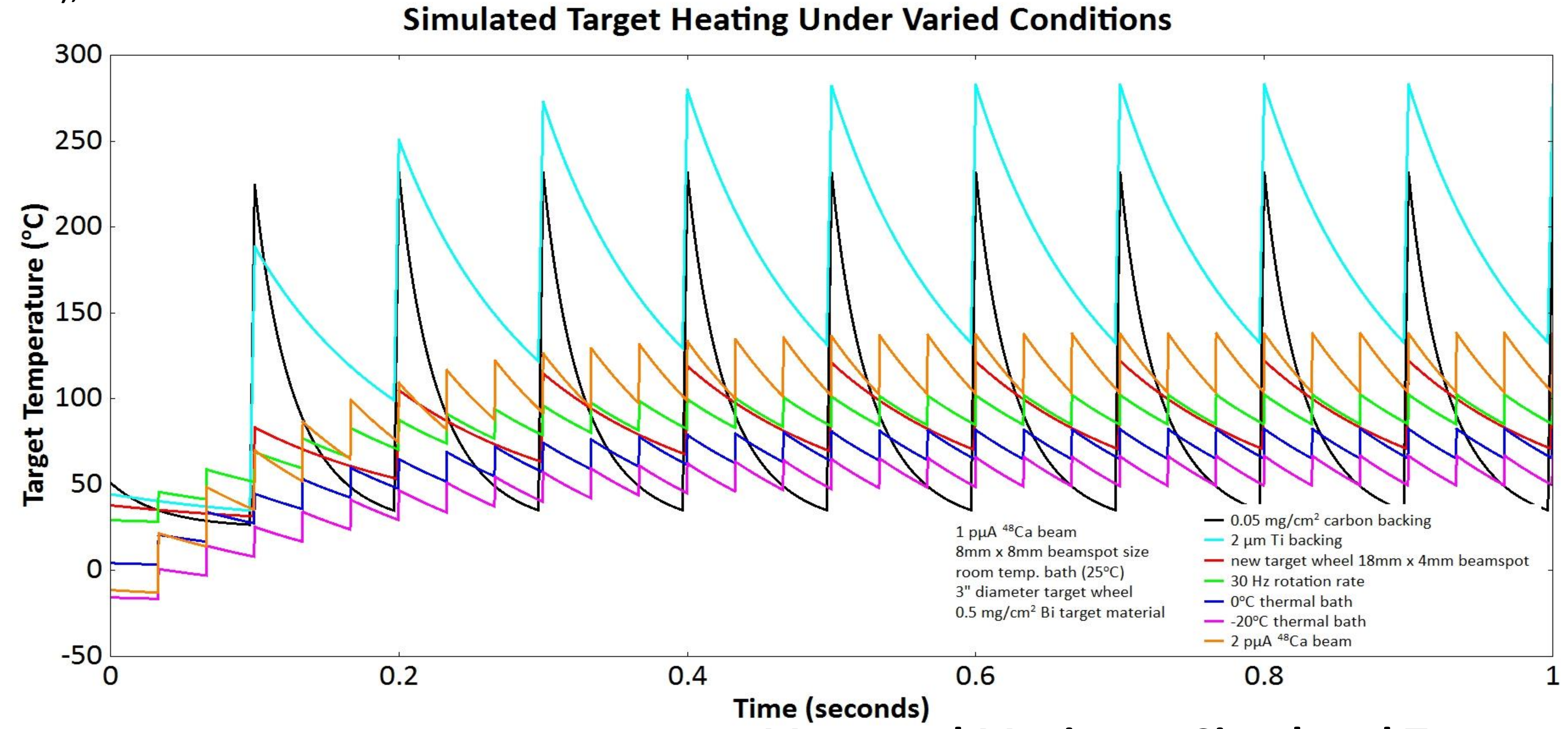
Simulated Target Heating in $^{243}Am_2O_3$ Target with Variable Beamspot Sizes



WIDER INVESTIGATION OF TARGET HEATING WITH SIMULATION

A wider investigation using computer simulations were conducted to better understand target heating during SHE experiments. Different backing materials, target wheel rotation frequencies, thermal bath temperature were considered and a new design were considered. **Below:** Plot of simulated targets under varied conditions. Initial conditions are presented in the plot. The legend describes different conditions changed for each run. After the carbon backing (black line), all varied conditions are cumulative.

Simulated Target Heating Under Varied Conditions



Investigation of other targets

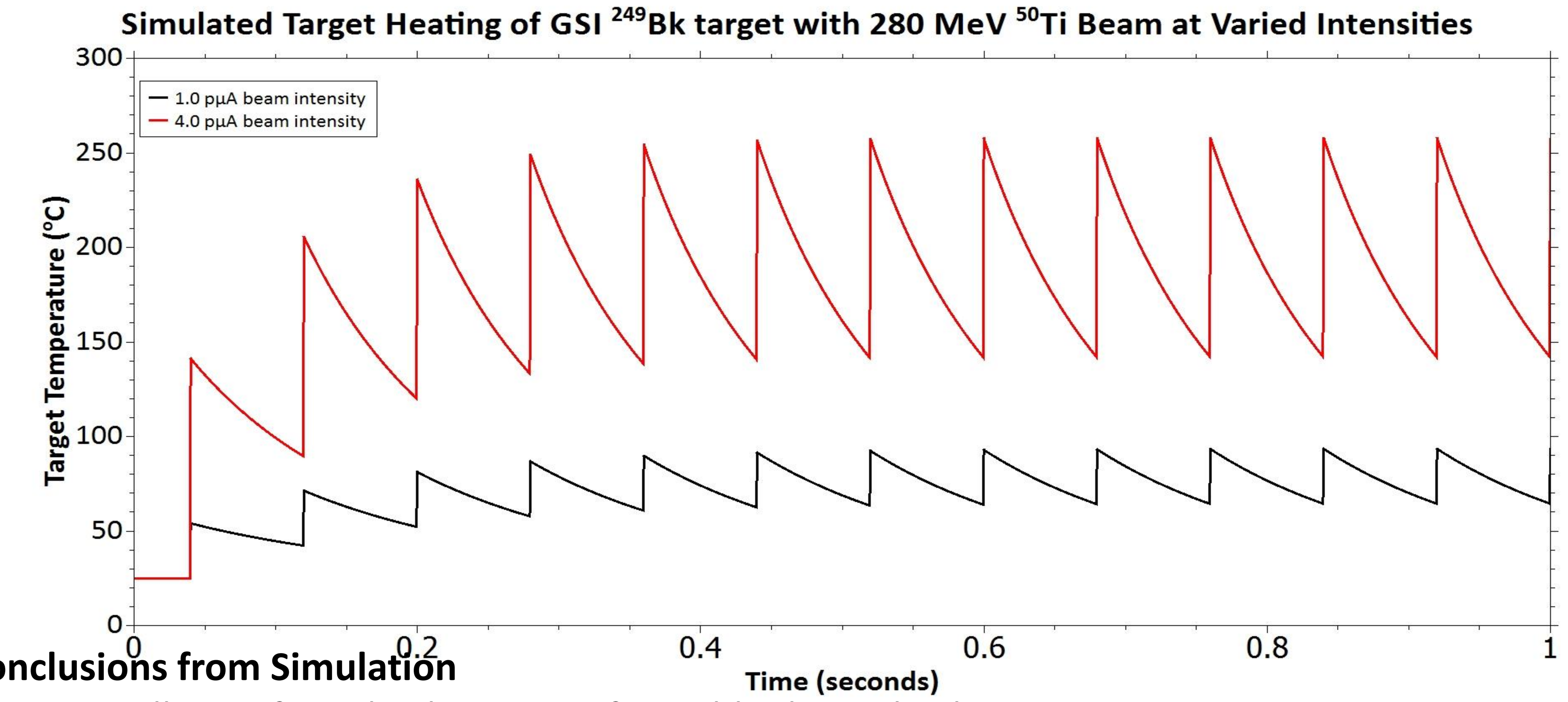
The issue of target integrity is shared by other facilities conducting SHE experiments (GSI, FLNR in Dubna, RIKEN). Simulations were used to investigate target heating in systems used by other facilities. The system at GSI is able to measure temperature in real time during and experiment and thus provided an excellent opportunity to compare simulation results to collected, experimental data.

Mean and Maximum Simulated Target Temperatures

Target Conditions	Mean Temperature (°C)	Max Temperature (°C)
Carbon Backing	88	232
Titanium Backing	195	283
Re-designed target	93	122
30 Hz rotation frequency	94	103
0°C thermal bath	74	83
-20°C thermal bath	59	67
2 pμA ^{48}Ca beam	121	138

Below: Simulated target heating for the element 119 experiment with TASCA@GSI. The UNILAC has a pulsed beam structure with a 25% duty factor at a 50 Hz repetition rate, so each of the four target segments on the wheel is irradiated for 5 ms with a 4 pμA beam pulse at 12.5 Hz. The simulated temperatures agree well with the measurements.

Simulated Target Heating of GSI ^{249}Bk target with 280 MeV ^{50}Ti Beam at Varied Intensities

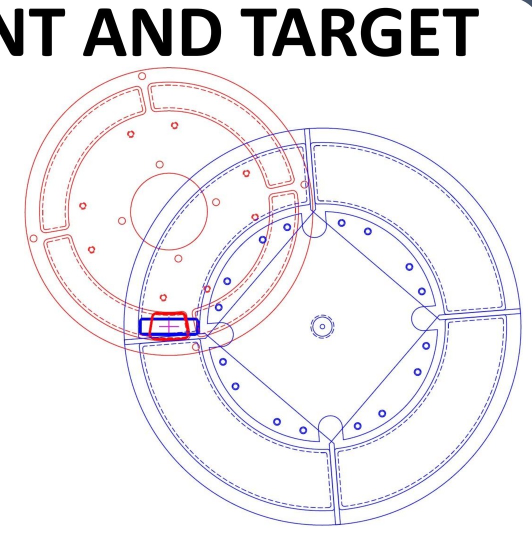


Conclusions from Simulation

- Smaller ΔT for Ti backing more favorable than C backing
- Re-designed target with rectangular beamspot drastically reduces average temperature in target
- Faster target wheel rotation frequency reduces peak temperature
- New target design can accommodate beam intensities up to 2.0 pμA

LAWRENCIUM-255 EXPERIMENT AND TARGET RE-DESIGN

Drawing from simulation, the target was re-designed and subsequently characterized in a recent experiment to probe the level structure of ^{255}Lr. While ^{255}Lr has been studied before, this study had access to higher intensity beams and a target to survive the bombardment, enabling higher statistics to be collected for analysis of the level structure of ^{255}Lr.

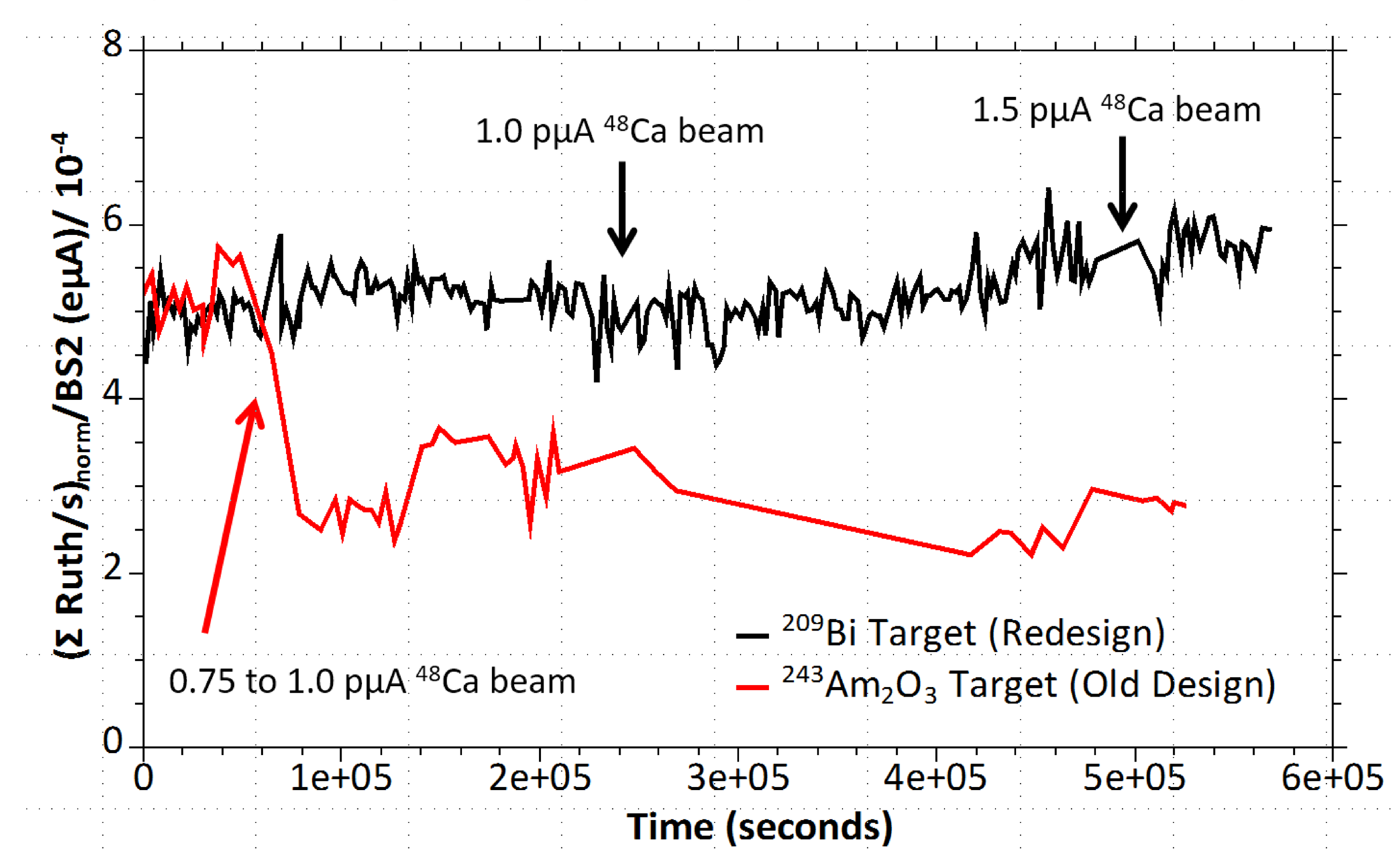


Above: Diagram of old design (red) and re-design (blue) of target. Beamspot sizes are in bold. **Left:** Table of notable characteristics of old target and re-designed target.

Old Target and Re-design Comparison

Target type	Target Area (cm^2)	Beam Width (mm)	Beam Height (mm)	Beam Area (cm^2)
Old	16.7	8.0	8.0	0.64
Re-design	55.7	18.0	4.0	0.72

Comparison of Target Integrity: ^{255}Lr Experiment vs. Element 115 Experiment



Above: Ratio of normalized Rutherford detector rates and beam current from upstream Faraday cup vs. irradiation time. Ratio infers target integrity over time. Note stability of redesigned target (black line) vs. decrease in ratio of old target (red line).

FUTURE WORK

- Use re-designed target in commissioning experiment of Facility for the Identification of Nuclide A (FIONA) in order to identify the mass number of SHEs
- Perform gas-phase chemistry on transactinides (Z > 104) using FIONA and the radiofrequency quadrupole (RFQ) trap
- Higher statistic nuclear structure experiments of the transactinide elements

REFERENCES AND ACKNOLEDGMENTS

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This work was supported by the National Nuclear Security Administration (NNSA) under award numbers DE-NA0001978 and DE-NA0000979. Portions of this work were performed at LBNL which is managed by the U.S. DOE under contract number DE-AC0205CH11231. J.S. is supported by a DOE NNSA Stewardship Science Graduate Fellowship under Contract No. DE-FC52-08NA28752. This material is based upon work supported by the National Science Foundation Graduate Research Fellowship under Grant No. DGE 1106400. The NMR instrument used for this work is partially funded by NIH grant 1S10RR016634-01.